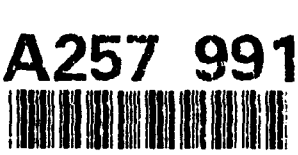

A RAND NOTE

Measuring the Burden of Alliance Activities

Gregory G. Hildebrandt

September 1990

RAND

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PREFACE

This Note discusses the problem of measurement of the burden of alliance activities. The study was undertaken through the Program for Integrating Economics and National Security funded by The J. Howard Pew Freedom Trust, one of The Pew Charitable Trusts. The research was conducted as part of RAND's International Economic Policy Program, in the National Security Research Division. It should be of interest to policymakers, economists, and others interested in measuring the burden of alliance activities borne by a member nation.

SUMMARY

The classical military-economic model of an alliance developed by Olson and Zeckhauser has been the traditional method for analyzing the contributions made by the alliance members. The model assumes that each member values the sum of the individual contributions. The sum can be viewed, therefore, as a pure-public good with nonrival consumption.

There are several reasons why it is appropriate to reconsider the Olson-Zeckhauser model. It has recently been observed that when a public good is provided by a number of individuals, redistributions of income among the group do not change the total quantity of the public good provided by all individuals, as long as each individual continues to contribute. Furthermore, there is no change in any person's consumption of other goods. As a result, each individual's welfare remains unchanged.

If one applies this result to the alliance context, the relevance of using defense spending per dollar of national income as a member's defense burden becomes questionable. Redistributions of income change a member's contribution by an amount equal to its change in national income. The defense burden of each would change, but there would be no change in any nation's welfare. The alliance members have a familial relationship that is difficult to decompose.

Another strain of analysis has indicated that many of the alliance goods provided by members are actually mixed-public goods that combine both private and public elements. Whereas the strategic forces that provide deterrence may be viewed as purely public, most conventional forces seem to contain both private and public components. A nation can select a command and control structure and deployment options that ensure that each unit of some conventional weapons type that it provides is worth more to it than an otherwise like unit provided by another alliance member.

It may also be legitimate to expand the definition of an alliance activity to include such categories as the economic aid provided to both members and nonmembers. The aid provided by an alliance member may have

a humanitarian component that is much like a pure-public good, but it also may serve to promote domestic export markets. The aid, therefore, has a private-public structure that needs to be accounted for when analyzing relative contributions.

We suggest a new measure of burden in the alliance context. This measure equals that part of a member's contribution that spills over to other members' divided by the member's full income. Full income is defined as the sum of national income plus that part of other members' contributions that spill over to the nation in question.

To evaluate this measure of the burden of a nation's contribution to alliance activities, however, it is necessary to determine whether neutrality is present. Although there is a special case in which neutrality is achieved with respect to total contributions, full neutrality occurs only in the Olson-Zeckhauser pure-public goods context. This indicates that the proposed burden measure is more relevant for mixed-public goods than it is for pure-public goods.

We also discuss empirical estimates of the spillover parameters. In one study, the United States seems to receive significant spillover from the NATO allies; the contributions of other members, however, are much like private goods. There are numerous uncertainties associated with such aggregate calculations. It is likely that interactions need to be assessed at a more disaggregated level using statistical (and other) techniques that properly reflect the lag structure of the interactions.

Further work is needed to properly identify a member nation's contribution. One research avenue would investigate specific characteristics of each member's alliance activities. By supplementing statistical methods with both surveys and subjective assessments, it should be possible to accurately implement the proposed measure of the burden of alliance activities borne by a member nation.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

The classic public goods model of an alliance introduced by Olson and Zeckhauser[1] has been used to analyze issues associated with the allocation and distribution of goods produced by alliance members. One of the central results of Olson-Zeckhauser's analysis is that rich nations are exploited by the poor because of a tendency for the poor to free-ride on the contributions of the rich. Indeed, they argue that the traditional measure of defense burden--the share of national income devoted to defense activities--reflects the inequities of the alliance relationship. There seems to have been little recognition, however, that the sort of pure-public goods described by Olson and Zeckhauser link alliance members in such an intimate relationship that the use of the traditional measure of defense burden in an alliance context, if not the Olson-Zeckhauser framework, needs to be reexamined.

A recent result by Peter Warr bears on this issue. If his analysis is applied to an alliance setting in which each member makes a positive contribution to the alliance's pure-public good, then although a redistribution of income would change each member's contribution, neither the total contribution of all members nor the welfare of any member would change. This is because each member's contribution becomes part of the other member's "full" income, which does not change as a result of the redistribution. Each member's well-being in this situation is neutral with respect to changes in the distribution of income that might occur, say, from changes in the private terms of international trade among the members. Conventional calculations of defense burden change, but nothing "real" changes when money income is redistributed.[2]

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[1]Mancur Olson and Richard Zeckhauser, "The Economic Theory of Alliances," *Review of Economics and Statistics*, Vol. 48, No. 3, August 1966, pp. 266-279.

[2]Peter Warr, "The Private Provision of a Public Good Is Independent of the Distribution of Income," *Economic Letters*, Vol. 13, 1983, pp. 207-211.

In the classic analysis of Olson and Zeckhauser, all of a member nation's defense activity is assumed to "spill over" to another member nation which consumes this good. There is, therefore, nonrival consumption of the defense activity provided by each member. Defense activity is thus a pure-public good in the classic Samuelsonian sense.[3]

Such a striking result may not be plausible to experienced observers of alliance interactions. These individuals have noted that redistributions of income that occur, say, through changes in the terms of trade among alliance members, have not resulted in commensurate changes in the contributions to the alliance. If they are correct, the traditional Olson-Zeckhauser model, with its assumption that alliance goods are pure public, may not be the appropriate framework for evaluating the behavior of member nations.

A new approach developed by Todd Sandler, Martin McGuire, and others extends the Olson-Zeckhauser framework by assuming that a nation's defense activity effectively contains both private and public elements and is, therefore, a mixed-public good. It is a private good in the sense that some part of defense activity does not spill over to alliance members; it is a public good in the sense that other members do value part of one's expenditure.

Interestingly, Todd Sandler and others have also argued that the strategy change from massive retaliation has decreased the public component of each NATO member's activities. They believe that NATO defense activities have become increasingly privatized.

This alternative view, if it is correct, has a bearing on the relevant measures of defense burden. We explore this analytical area, and suggest a new measure of burden equal to the share of the alliance activity of one member that spills over to other members of the alliance, divided by the sum of national income plus the benefits provided by other members that spillover to the member in question. We call the sum of national income plus these "spillins," the full income of a nation, and show that while calculations of burden remain dependent

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[3]Paul A. Samuelson, "The Pure Theory of Public Expenditure," *The Review of Economics and Statistics*, Vol. 36, 1954, pp. 387-89.

on income distribution in this situation, one does not obtain the sharp neutrality that applies to pure-public goods.[4]

Throughout our analysis we assume that the membership in the alliance is settled, and the number of countries in the alliance is, therefore, fixed. We also abstract from issues associated with the enforcement of agreements or the punishment of deviant behavior. The membership issue might be addressed, in part, using the theory of clubs. However, a full analysis of membership and the issues associated with enforcement or punishment must ultimately be addressed using the modern tools of noncooperative game theory. Such an analysis, however, is beyond the scope of this study. We use the traditional approach in which each member selects its contributions contingent on those of other members. The outcome of such a process is called a Cournot-Nash equilibrium in the economics literature. The effect of changes in the income of each participant is then assessed using the method of comparative statics.[5]

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[4]For a discussion of mixed-public goods, see Todd Sandler, "Impurity of Defense: An Application to the Economics of Alliances," *Kyklos*, Vol. 30, 1977, pp. 443-460, and Martin McGuire, "Mixed Public-Private Benefit and Public-Good Supply with Application to the NATO Alliance," *Defence Economics: The Political Economy of Defence Disarmament and Peace*, Vol. 1, No. 1, 1990, pp. 17-36. The privatization of alliance goods is discussed in James C. Murdoch and Todd Sandler, "Complementarity, Free Riding, and the Military Expenditures of NATO Allies," *Journal of Public Economics*, Vol. 25, 1984, pp. 83-101. For a policy discussion that addresses the privatization issue, see Brian Field, "Economic Theory, Burden Sharing and the NATO Alliance," *NATO Review*, December 1988, pp. 11-15. An alternative approach has been developed by Robert Kuenne, who argues that in mature cooperation or rivalry, a nation cares not only about its own benefits and costs, but also about those of its ally or adversary. See Robert Kuenne, "Conflict Management and the Theory of Mature Oligopoly," *Conflict Management and Peace Science*, Spring 1988, pp. 37-58.

[5]The theory of clubs is discussed in Richard Cornes and Todd Sandler, *The Theory of Externalities, Public Goods, and Club Goods*, Cambridge University Press, 1986, pp. 157-244. For a discussion of recent developments in noncooperative game theory, including a modern view of Nash equilibrium and the Cournot-Nash special case, see Eric Rasmusen, *Games and Information: An Introduction to Game Theory*, Basil Blackwell, Inc., 1989.

II. COST OF U.S. NATO CONTRIBUTION

We first discuss one approach to measuring a nation's contribution that has been employed by the U.S. Department of Defense. The focus has typically been on the cost rather than the benefit side of the equation, and has taken the vantage point of a hypothetical decisionmaking margin to allocate defense costs to alliance support. Table 1 provides alternative cost estimates provided to Congress by the Department of Defense in 1985 that are applicable to the Europe context. One might also add that these estimates are relevant to a possible reduction in U.S. forces deployed to Europe.

Clearly, alternative estimates of the incremental cost of the U.S. contribution to NATO's defense vary significantly. The estimate depends on what one defines as the appropriate margin and ranges from the incremental cost of the troops deployed to total defense spending. It has been argued, however, that approximately 60 percent of U.S. defense activities can be associated with NATO. Presumably, this estimate is derived from No. 5 of Table 1.[1]

This measure of cost, which actually computes to slightly less than 58 percent, includes the direct cost of operating and supporting those forces deployed or committed to NATO; an allocated share of the cost of new equipment; and a proportionate share of the costs of U.S based training and logistics support, research, development, test, and evaluation (RDT&E), and DoD administration.

An interesting question is the applicability of these types of cost estimates for analyzing the issue of burden-sharing. Although it may be reasonable to assume that some part of U.S. defense spending should not be attributable to NATO in burden calculations, it is not clear that our NATO allies discount U.S. defense spending to, say, 60 percent of the total. The percentage of U.S. expenditures that spill over to NATO depends on a host of different factors.

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[1]Representative Patricia Schroeder, reported in New York *Times*, April 6, 1988.

Table 1

THE U.S. COMMITMENT TO EUROPE'S DEFENSE COST ESTIMATES FOR FISCAL YEAR 1985--TOTAL OBLIGATION AUTHORITY

	Approximate Annual Cost	Description of Cost Category
1.	$2 billion	The *incremental* operating cost incurred by stationing U.S. forces in Europe rather than in the United States
2.	$15 billion	The *incremental* operating cost associated with maintaining European-deployed U.S. forces in the *active* force structure
3.	$55 billion	The *total* cost of European-deployed U.S. forces
4.	$90 billion	The *total* cost of European-deployed U.S. forces and those U.S.-based forces that we have pledged to contribute as NATO reinforcements in the early stages of a conflict
5.	$177 billion	The *total* cost of European-deployed U.S. forces and all of the U.S.-based forces that we have pledged to contribute as NATO reinforcements over the course of a conflict
6.	$227 billion	The *total* cost of all U.S. conventional forces
7.	$306 billion	The *total* cost of all U.S. forces

SOURCE: Alice C. Maroni and John J. Ulrich, *The U.S. Commitment to Europe's Defense. Overview of Cost Issues and Estimates,* Congressional Research Report No. 85-211 F, November 7, 1985. The information was provided to Congress by DoD in June 1984.

U.S. commitments to NATO are the outcome of a planning process that employs a specified scenario, but in fact, there is a wide range of European theater contingencies in which the NATO allies would value U.S. forces. These would include contingencies that require much less than or far greater than 60 percent of current U.S. forces. Furthermore, U.S. security commitments outside the European theater can have an effect on the probability of a war in Europe. The NATO allies, therefore, may value U.S. defense efforts directed toward these other regions.

This suggests that, when focusing on the issue of burden-sharing, it is more appropriate to allocate cost by estimating the benefits that alliance members derive from each nation's defense activities. In addition, imputations of benefits are best made at the margin where resource allocation decisions take place. Therefore, rather than allocating cost based on the resource implications of some canonical scenario, it is more relevant to address how the NATO allies value an additional dollar of a particular type of U.S. defense spending. A similar calculation might be made for the U.S. valuation of the allies' efforts. This suggests that the mixed-public goods analysis discussed above is applicable.

III. ALLIANCE ACTIVITIES

Even though the security dimension of an alliance has frequently been emphasized in those situations in which the creation of a common defense is the basis for its founding, there is a wide range of activities undertaken by alliance members that generate consumption benefits for the other member nations. At one end of the spectrum, there are certain types of defense goods whose character to the alliance is pure public. These are goods for which there is inherently nonrival consumption; coterminously, exclusion is nonfeasible.

Deterrence is an example of such a good. When one nation produces the military asset that provides this good, the probability of war fought by the alliance is reduced, and all members benefit. It does not matter which nation is producing the asset that yields the deterrence; every member aggregates the individual contributions of all the member nations when evaluating the asset. If, as an example, each member perceives that a reduction in the probability of war is directly related to the sum of the strategic warheads provided by all the alliance members, this sum is a pure-public good.

For many defense goods, however, particularly those associated with conventional forces, the character of the deployment of the forces, the positioning of operational reserves, the collection and dissemination of intelligence information, and other detailed defense activities have both private and public components. To the extent that these activities provide a general deterrence effect, they would be much like the benefits provided by nuclear forces. To the extent, however, that specific characteristics of these goods generate a higher level of defense activity for the provider than they do for other member nations, the goods contain a private element. Most of the examples drawn from the nature and application of conventional force seem to fall into this mixed category.

Effectively, the situation is one in which a tank produced by one's own defense establishment is treated as a larger unit of defense activity than a like tank produced by other members. This type of defense good, therefore, has both public and private components. It is public because a part of each member's conventional weapons spillover to other members; it is private because a part of these assets is effectively consumed only by the member providing them.

There are other alliance activities in which this type of situation occurs. For example, consider the economic aid provided to countries outside the alliance. In addition to public characteristics of this aid such as the humanitarianism provided, or the promotion of common political values, there are other characteristics that are predominantly private. The economic aid might affect the creation of export markets to the provider, or assist in the debt repayment to domestic banks.

The private-versus-public structure of an alliance activity depends primarily on the particular characteristics of the activity that are emphasized by the provider. If, in the aid example, characteristics that contribute to the creation of domestic markets are promoted at the expense of humanitarianism, a smaller part of the aid would be valued by other nations than if the primarily humanitarian characteristics are emphasized. Effectively, the nation providing the aid with a high private-to-public structure is excluding the other nations from consuming some of the activity. The exclusion and degree of publicness, however, are produced simultaneously, and it is not possible to separate them.[1]

It may also be the case, however, that the recipient of the spillovers can control their size. If one nation designs a tactical air force with extensive communications, command, control, and intelligence

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[1]There are also activities undertaken by alliance members that yield private gains generated by the interaction of alliance members. For example, there are gains from private trade among the alliance members. To the extent, however, that these gains are not derived from the alliance's existence, it may not be admissible to consider them as part of "alliance" activities. They are, nevertheless, part of the surplus generated in the interaction among alliance members.

(C^3I) assets, but some other nation fails to design its own equipment to fully take advantage of this C^3I capability, then both nations are affecting the size of the spillovers through their actions.

IV. NEUTRALITY AND THE BURDEN OF A MEMBER NATION

With such a wide range of activities provided by each alliance member that generate spillovers to other members, the calculation of the activities' burden to a member nation is complex. The most widely used measure of burden is the share of national income devoted to defense (or more broadly alliance) activities. If one abstracts from issues of alliance interaction, this is a useful descriptive statistic. Defense spending is a first-order approximation of other things being forgone that could have been consumed with the resources devoted to defense. The ratio of defense spending to national income, therefore, measures the opportunity cost of defense activities relative to national income--the proportion of national income that could have been devoted to other activities.

We first discuss some aspects of the defense-burden indicator for the case in which each member nation consumes a pure-public good. Particular attention is paid to the relationship between this indicator and the neutrality results of Peter Warr. Then we address the case in which the alliance member's contribution contains both private and public elements. For ease in illustration, we discuss this issue for an alliance with two members. Generalizing to more than two members is, however, straightforward.

PURE-PUBLIC ALLIANCE ACTIVITIES

Consider, first, the classic pure-public good situation that is, as we have indicated, best exemplified by deterrence. The sum of the two members' contributions to this alliance activity is valued by each member. This pure-public alliance good, X, is provided in quantities X_a and X_b by the two members, A and B. The total quantity of the two goods produced, $X = X_a + X_b$, cannot be subdivided in consumption; the amount supplied by one fully spills over to the other. The quantity, X, therefore, is valued by both alliance members who possess preference indicators, $U_a(Y_a, X)$ and $U_b(Y_b, X)$, where Y_a and Y_b represent the

consumption of the "other" non-alliance goods. We assume that both X and Y are normal goods for both countries, and that each of the alliance members contributes to the alliance.

Because our focus is on the demand side of the alliance equation, we assume that the two members face a common, constant price for the alliance good in question. We can, therefore, adjust the units of X so that the quantity of the alliance good provided equals the expenditure on this activity.

The expenditure on non-alliance goods equals respective money income of members A and B, I_a and I_b, less the individual contribution to the alliance. It is helpful in this discussion to recognize that the expenditure on alliance goods equals the total provided by both members of the alliance less the amount provided by others. For A, this would be $X - X_b$. The consumption of non-alliance goods, therefore, equals the income of the member in question, plus the alliance activities provided by others, less the member in question's own contribution. This permits us to write the two preference indicators as follows:

$$(1a) \qquad U_a = U_a(I_a + X_b - X, X)$$

$$(1b) \qquad U_b = U_b(I_b + X_a - X, X).$$

We can see from these equations that each nation effectively has a full income that includes not only domestic national income, but also the other member's contribution. Each nation can, therefore, be viewed as choosing the level of X (by adjusting its contribution) to achieve its national objectives.

It might be helpful to illustrate the decisionmaking process of an individual nation graphically. Figure 1 depicts nation A's selection of its optimal contribution with increases in nation B's contribution. Country A's preferences for private good, Y_a, and the public good, X, are represented by indifference curves U^o, U', and U'' that apply to increasing levels of national well-being.

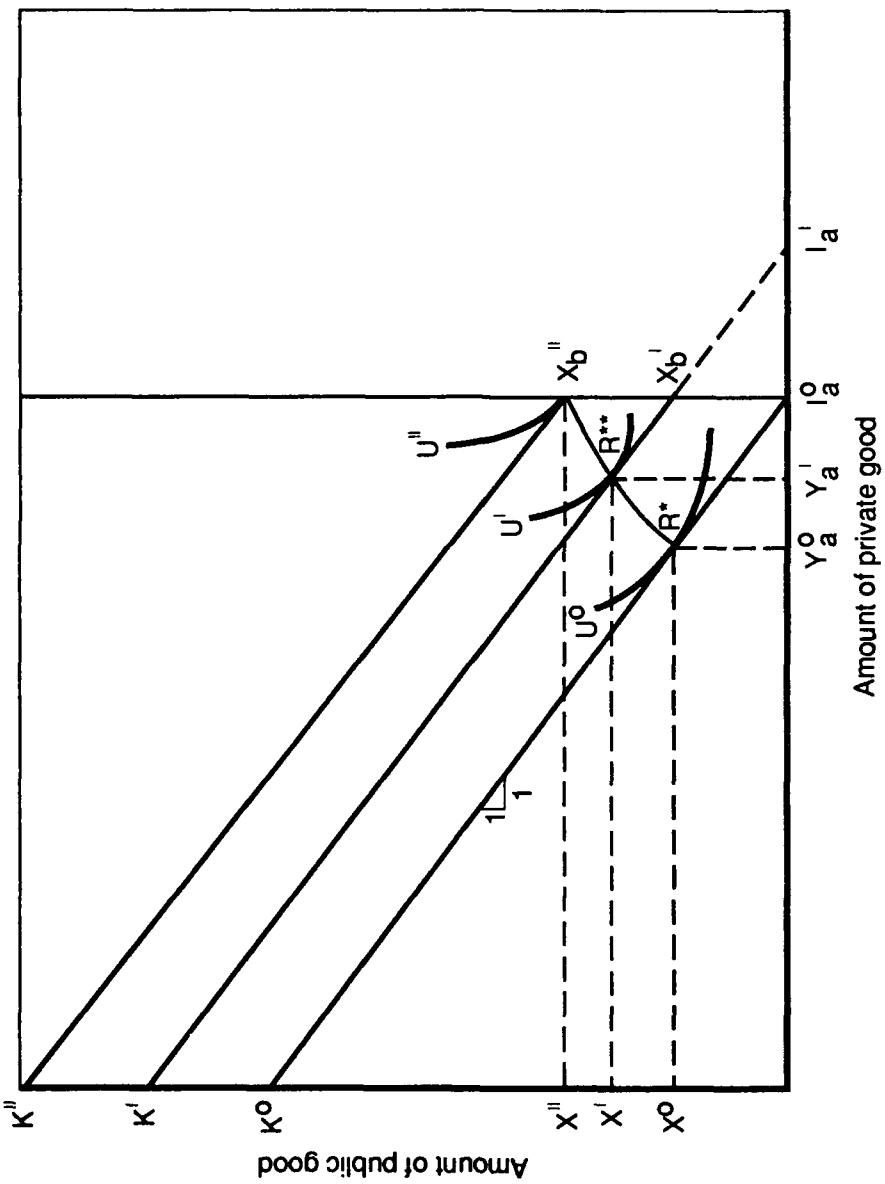

Fig. 1—Determination of contribution by member nation

When B does not make a contribution to the public good, the production possibility curve describing A's ability to convert the private good into its public good contribution is represented by $I_a^o K^o$, where I_a^o is A's initial level of monetary national income. The slope of this line equals -1 under our assumption that we measure the quantity of the public good using the unchanging price equal to one unit of the private good.

Nation A selects point R^* and consumes a level of the public good equal to X^o. Because B is not making a contribution, A's production of the public good equals its consumption.

It is interesting to notice what happens when B contributes to the public good, say, level X_b' in Fig. 1. Note the dashed line continuing down to I_a'. As the slope of line segment $I_a'X_b'$ equals -1, distance $I_a^o X_b'$ equals distance $I_a^o I_a'$ and the specified contribution by B, is viewed as equivalent by A to increase in income X_b'.

Either the designated public good increase or income increase will result in the selection of point R^{**} by the member nation. It is for this reason that country A's full income in the situation described is $I_a^o + X_b'$. At this level of full income, A can be viewed as selecting level of public good consumption X'.

Also notice that while A's consumption level of the public good rises with B's contribution, its own contribution decreases. A has begun to free-ride on B's contribution. As B continues to increase its contribution, eventually A will chose not to contribute. In Fig. 1, this occurs when B contributes X_b''. At this level, A's contribution decreases to zero and its consumption equals B's contribution. A now gets a full free ride from B in its consumption of the public good.

In our core analysis, however, we are abstracting from the possibility that a corner solution in which only one member contributes occurs. For Warr neutrality to apply, both alliance members must make some contribution to the public good. For broad aggregates of activities, such as defense spending, this is probably a reasonable assumption. However, for very specific types of expenditures, such as those on ICBMs by alliance members, this assumption may not be tenable.

Also, for certain types of activities such as the provision of economic aid, substantial wealth disparities between the members may result in only wealthier members making a contribution. Nevertheless, we continue to focus on the situation in which each member contributes something.

We can now show directly why Eqs. (1a) and (1b) imply that the optimal value of X selected by A and B will depend only on the respective levels of full income. First, let the functions determining this X be designated f_a and f_b for A and B, respectively. In equilibrium, both countries must be selecting the same level of X, so that the following relationship must hold:

$$(2) \qquad f_a(I_a + X_b) = X = f_b(I_b + X_a).$$

A careful examination of Eq. (2) permits us to show that redistributions of the total national income, $I = I_a + I_b$, between the two members result in like changes in defense contribution such that X remains unchanged.

To show this, first notice that when a redistribution of income from the other nation to the member in question takes place, the gaining member will increase its contribution to the alliance to offset the other member's reduction. Certainly, one possible outcome occurs when the reduction in the other member's contribution just equals its reduced income. If this happens, there will be no change in full income and the receiving nation will use the extra income to obtain the same total of alliance goods as before the redistribution. Such behavior will then cause the other to react similarly, and there will be no change in the level of public goods provision. We conclude, therefore, that this outcome is an equilibrium. Each nation is optimally selecting the same total level of the public good given the other member's contribution. While the *composition* of the total changes as a result of these redistributions, there is no change in either the level of alliance or non-alliance goods that each of the two members consumes.

It is also interesting to consider why no other outcome can be an equilibrium. We illustrate this by describing a hypothetical adjustment process following a redistribution of income.

The income transferring nation will first experience a decrease in full income and will reduce its contribution to the alliance. The reduction in contribution will, at first, be less than the income transferred, and the receiving nation will experience a rise in full income. As a result, the receiving nation will increase its demand for the public good. Its contribution, therefore, will initially rise. Equilibrium can only occur and Eq. (2) be satisfied, however, when the change in money income translates into a corresponding change in each member's contribution to the alliance. We conclude, therefore, that the total provision of a pure-public good that is provided through the contributions of individual members does not depend on the distribution of income among the members.[1]

Once again we can illustrate graphically what is happening. To simplify the presentation somewhat, it is helpful if we assume that the marginal propensity to spend income on the public good is a constant for each nation. For A and B respectively, we designate these propensities as $1 - \gamma_a$ and $1 - \gamma_b$.

Suppose that the isolation spending on the good, that is, the expenditure when there is no contribution by the other alliance member, is linear in national income. For example, the isolation spending of A would be $K_a + (1 - \gamma_a)I_a$.[2]

The contribution of B, X_b, however, augments A's full income by an equal amount. There is, therefore, an additional demand by A for X of $(1 - \gamma_a)X_b$. With B contributing the amount X_b, however, A will reduce its contribution by $\gamma_a X_b$. We have a parallel situation for B, and can,

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[1]The uniqueness of equilibrium is formally proved by Theodore Bergstrom, Lawrence Blume, and Hal Varian, "On the Private Provision of Public Goods," *Journal of Public Economics*, Vol. 29, 1986, pp. 25-49. Recall that we are assuming, as do Bergstrom et al., that both the public and private goods are normal. The author is indebted to Jack Hirshleifer for alerting him to the existence of the neutrality theorem.

[2]This might best be viewed as a first-order approximation of a non-linear function.

therefore, express the reaction functions describing each country's contribution to the public good as follows:

$$(3a) \quad X_a = K_a + (1 - \gamma_a)I_a - \gamma_a X_b$$
$$(3b) \quad X_b = K_b + (1 - \gamma_b)I_b - \gamma_b X_a.$$

Figure 2 plots the two reaction functions for A and B, R_a^o and R_b^o, for some initial distribution of income, I_a^o and I_b^o. Reaction curves R_a' and R_b' for a new income distribution I_a' and I_b', obtained by transferring ΔI from B to A, are also shown.[3]

Under the initial distribution of income, the Cournot-Nash equilibrium of the member's *contribution* is represented by point Q*. The dashed 45^o line indicated on the graph has the interesting property of identifying on the horizontal and vertical axes the *consumption* of the public good, X. The points of axes intersection, X*, are obtained by adding the contribution of the two nations.

We can now illustrate what happens with an income transfer of ΔI from B to A. The focus is on the effect of the change from the perspective of country A; a symmetrical opposite effect occurs for B. The reduction in B's income reduces its contribution by ΔI. Such a reduction, by itself, motivates A to move along its original reaction curve by increasing its contribution by $\gamma_a \Delta I$. But the increase in income also induces an extra contribution of $(1 - \gamma_a)\Delta I$; it shifts the reaction curve for A out by this amount. The total effect, therefore, is an increase in contribution by A of ΔI. With an equal reduction by B, the total provision of the public good remains unchanged. As shown, the new equilibrium, Q**, remains on the 45^o line so that the consumption of the public good remains as before the income redistribution. In sum, while redistributions of income move nations along the 45^o line as their contribution changes, this line itself does not shift, and the consumption of the public good by each nation remains unchanged.

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[3]The use of the 45^o line to represent public good consumption is taken from Jack Hirshleifer, *Price Theory and Application,* 4th ed., Prentice Hall, 1988, p. 507.

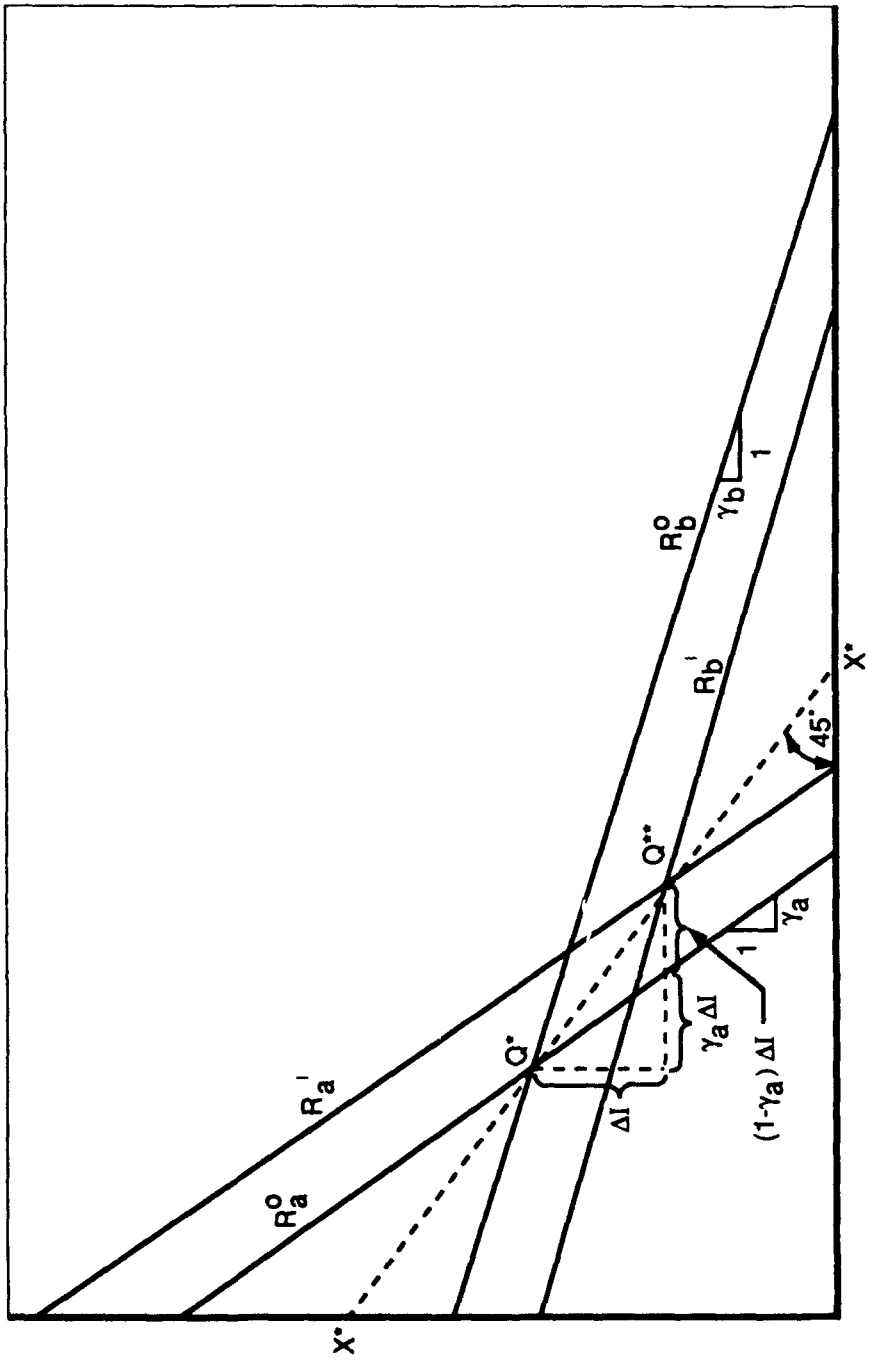

Fig. 2—Nash–Cournot equilibrium for two alliance members

From Eqs. (1a) and (1b), it is also evident that, with each nation's full income unchanged, and the total provision of the public good remaining constant, the consumption of non-alliance goods does not change. Each country's welfare, therefore, must remain unchanged. But this is just another way of saying that full income is not affected by the income redistribution. In this pure-public goods situation, full neutrality is achieved as discovered by Peter Warr.

An important question, therefore, is the usefulness of the ratio of defense spending to money income as a measure of defense burden for each alliance member. Redistributions of income change each member's contribution to the alliance, and in turn, the calculated "burden" ratio, but do not change the welfare of any member.

An implication of this discussion is that we can express the *total* provision of the alliance good as a function of the *total* money income of the two alliance members:

$$X = f(I). \tag{4}$$

It is as if the total quantity of the alliance good is provided by a single nation with income, I. The pure-public nature of the alliance good and the individual provision of quantities of this good induce a familial relationship among the alliance members that is difficult to decompose into relative contributions.

As indicated above, changes in the terms of trade can affect the distribution of income among the alliance members. Over time, there may also be differences in the rate of economic growth. Therefore, both trade and growth affect the size and distribution of income across nations as the relative endowments change and are redistributed. Yet, if the preference indicators of the two countries remain unchanged, Eq. (4) continues to apply. The additions to X will depend on the incremental aggregate money income of the alliance members in accordance with the function f.

Suppose we take this analysis a step further than Warr, and assume that both members have the same preference for alliance and non-alliance activities. While the utility indicators are identical, the money income of each nation may differ. Once again, the level of X consumed by each nation will be the same. But in this case, so too will the consumption of the non-alliance goods, Y_a and Y_b. The reason is that, with identical tastes, the level of X selected by each will be the same only if each nation's full income is the same. With the same full income, the consumption of the non-alliance goods must also be the same. With identical preferences, and each member providing some of the public good as assumed, real income will be equalized even when there are differences in money income.[4]

To determine whether such an outcome represents a fair distribution of the alliance burdens is beyond the scope of this analysis. Ultimately, the "fair" outcome depends on the nature of the social welfare function employed for the alliance. There are, however, two important types of welfare functions that relate to this issue.

One type, a neoclassical Bergsonian welfare function, expresses alliance welfare as a function of the full income received by each member. It does not give any weight to the changes in income relative to some initial situation, but rather evaluates the final outcome.

A second type of welfare function, derived from cooperative game theory, expresses welfare as a function of each member's full income in equilibrium less the income received in some initial or reference situation. In this case, it is the change in full income resulting from alliance activity that is evaluated. The two most widely known functions of this type are the Nash and Shapley bargaining solutions.[5]

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[4]Differences in population imply that per capita real income would not be equal in the two countries.

[5]For a discussion of the neoclassical Bergsonian welfare functions, see See Jack Hirshleifer, *Price Theory and Applications*, Chap. 15. The Nash and Shapley bargaining solutions are discussed in R. Duncan Luce and Howard Raiffa, *Games and Decisions: Introduction and Critical Survey*, John Riley & Sons, 1957, Chap. 6.

The difference between the two types is central to the issue at hand. If tastes are identical and a symmetric Bergsonian social welfare function is employed, such that an equal division of some level of total alliance full income is preferred to an unequal division of that level of total income, then equal real income might be judged desirable. This is the case even though there are significant differences in the initial situation.

One criticism of this approach, therefore, is that it abstracts from the *changes* in full income received by each member at the same time as these changes depend on the other member's contribution. The Nash and Shapley solutions would take account of these changes. In addition, the symmetric treatment of the two members would yield equal shares of the total increment of full income generated by the alliance.

For example, suppose one specifies the reference point as the level of isolation income before the formation of the alliance, when each nation's full income equals money income. Then, if the equal full income equilibrium outcome is achieved, the poor nation will have clearly gained more than the rich. This happens because a larger contribution by the rich nation increases the poor nation's full income correspondingly. Such outcomes would not be acceptable in either the Nash or Shapley solutions, which require symmetry with respect to the income increments.

In this analysis, we do not provide an evaluation of these alternative approaches. One important point, however, needs to be made. If indeed we restrict ourselves to static Cournot-Nash behavior, then it is clear from the discussion of neutrality that transfers in money income among alliance members cannot alleviate any identified inequities in the welfare of the members. To sustain an equitable alliance outcome, a process other than Cournot-Nash must be employed.[6]

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[6]The author is indebted to John Nachbar for discussions of this point.

MIXED ALLIANCE ACTIVITIES

Whereas the classical model has emphasized pure-public alliance activities, we would expect most national activities in support of an alliance to contain both private and public characteristics. This occurs when the alliance goods produced by each member do not fully spill over to the other members.

As indicated above, a country providing economic aid may evaluate the aid fully, but other alliance members may not. The provider has personnel in the country who can obtain information about export markets, etc. Following Martin McGuire, suppose that the total amount of this alliance good consumed by country A equals $X_a + \phi_b X_b$. Country A values its own good fully, but discounts B's production. We have identified the spillover parameter, ϕ_b, using the subscript of the nation providing the good to suggest that this country may have the most significant control over the size of this parameter. As discussed above, however, the behavior of both nations can affect the size of this parameter. Whenever the contributions of the two alliance members are substitutes, as one would expect when the contributions are for a broad activity level, $0 \leq \phi_i \leq 1$, for $i = a, b$.[7]

For this mixed-public good situation, country A's preference function is written $U_a(Y_a, X_a + \phi_b X_b)$. Member B's would be represented by $U_b(Y_b, X_b + \phi_a X_a)$.

Although we can derive the spending functions of each nation by maximizing these utility functions subject to the relevant national income constraints, it is possible to obtain the spending functions more directly for a generalization of the constant marginal propensity situation presented above in Eqs. (3a) and (3b).

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[7]This conceptualization of mixed-public goods in an alliance setting has been employed by Martin C. McGuire in "Mixed Public-Private Benefit and Public-Good Supply with Application to the NATO Alliance," op. cit. We discuss below a situation in which alliance activities are complementary such that an increase in the contribution provided by one member increases the supply provided by the other.

In the mixed-public good situation, the contribution of B, X_b, augments A's full income by an amount $\phi_b X_b$, at the same time as it leads to a reduction in X_a by $\gamma_a \phi_b X_b$. Given the parallel situation for B, the reaction functions for the two countries would now be applicable for the mixed-public goods:

$$(5a) \quad X_a = K_a + (1 - \gamma_a) I_a - \gamma_a \phi_b X_b$$
$$(5b) \quad X_b = K_b + (1 - \gamma_b) I_b - \gamma_b \phi_a X_a.$$

These equations are extremely interesting because they provide a well-defined empirical method for estimating the spillover parameters ϕ_a and ϕ_b. In addition, it is possible to solve these equations simultaneously to obtain X_a and X_b as a function of the Ks, each member's national income, and the spillover and marginal propensity to spend parameters.

Let us now consider a possible measure of burden in this mixed-public good situation. We first define a member's contribution as that part of total spending that spills over to the other member.[8] The remaining part is a private good, which should probably not be admissible in burden calculations. At the same time, each country's expenditure on the alliance good can be viewed as coming from full income, which equals national income plus the discounted expenditure of the other member. We suggest, therefore, the ratio of one member's expenditures that spill over to the other member divided by the one member's full income as a measure of burden. For A and B, we would calculate the following ratios:

$$(6a) \quad H_a = \phi_a X_a / (I_a + \phi_b X_b)$$
$$(6b) \quad H_b = \phi_b X_b / (I_b + \phi_a X_a).$$

[8] If there are more than two members of the alliance, one would need to calculate an average amount that spills over to other members.

If one nation structures its spending so that its activities are primarily private at the same time as it receives a substantial amount of spillover from others, its calculated burden would be low. On the other hand, the other nation's numerator would contain these "spillins." That country's full income, however, would be predominantly national income, and this would tend to raise its calculated burden.

One attractive feature of the proposed measure is that both members' spillover parameters enter the burden calculation of each member. As we have indicated above, each of these parameters may be affected by the behavior of both nations. The parameter, ϕ_b, that A uses to discount B's contribution may be primarily determined by the set of characteristics selected by B (location of units, mobility capabilities, etc.), but it is also affected by the characteristics selected by A (commonality of spare parts, interoperability, etc.).

What, however, is the effect of income redistributions on the member's contributions? In the pure-public goods model, defense spending changes as income is redistributed, but full income (and therefore welfare) remains constant. In the mixed-public goods setting, on the other hand, the effect of income distributions on the contributions of members and other consumption is complex. This issue has been analyzed in a more general context by James Andreoni, who explores the effect of income redistributions on the sum of the members' contributions, $X = X_a + X_b$.[9]

To analyze this issue, Andreoni defines a parameter, α_i, in this case i = a, b, which is equal to the (partial) change in X with respect to a change in own income divided by the (total) change in X with respect to a change in the other member's contribution. The parameter measures the marginal rate of substitution between the other member's contribution and the money income of the member nation in question when the total provision of X is held constant. We will call this parameter the Andreoni coefficient.[10]

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[9]James Andreoni, "Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving," Department of Economics, The University of Wisconsin--Madison, July 1989.

[10]Andreoni's analysis is presented in the context of charitable

In the specific case assumed in Eqs. (5a) and (5b), one can readily show that the following Andreoni coefficients are applicable:

$$(7a) \qquad \alpha_a = (1 - \gamma_a)/(1 - \gamma_a\phi_b)$$
$$(7b) \qquad \alpha_b = (1 - \gamma_b)/(1 - \gamma_b\phi_a).$$

To understand how this ratio varies with different types of goods, consider first the pure-public good. In this situation, $X = X_a + X_b$ enters the preference indicator of each member, and an increase in money income for A just compensates for a similar decrease in X_b. This is because, with full income constant, the individual spends the extra income to maintain the same level of X. Stated somewhat differently, other things equal, there is an identical change in X with respect to a unit change in *either* I_a or X_b. The Andreoni coefficient, α_a, therefore, equals 1.

On the other hand, in the pure-private good situation, X_b does not enter A's preference indicator and the Andreoni coefficient equals the marginal propensity to contribute. This is because, other things equal, the change in X equals the change in X_b and the denominator of the coefficient equals one. The numerator equals the marginal propensity to contribute because this is the change in X from a unit change in I_a.

Finally, consider a mixed-public good in which the marginal propensity to contribute is the same as for the pure-public and private goods. The Andreoni coefficient for the mixed good must be greater than its value for the private good and less than one, the relevant value for a pure-public good.

To see this, take the perspective of country A and consider why the partial change in X with respect to a change in own income, $1 - \gamma_a$, is less than the total change in X with respect to the other member's

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giving; he calls the statistic the "altruism" coefficient. He views an individual who cares about only the total provided as altruistic, the individual who cares about only his own contribution as egoistic, and the individual who cares about both the total and his own contribution somewhere between the egoist and the altruist. The latter case is the mixed-public goods situation.

contribution. When member B contributes an additional dollar's worth of the good, Eq. (5a) indicates that A's contribution will decrease by $\phi_b \gamma_a$. The increase in X, therefore, is B's additional contribution of a dollar less the reduction by A, or $1 - \phi_b \gamma_a$. Because ϕ_b and γ_a are both less than one, the numerator of the Andreoni coefficient, $1 - \gamma_a$, must be less than the denominator, $1 - \phi_b \gamma_a$.

It follows immediately that the Andreoni coefficient for the mixed public good case must lie between the respective coefficients for private and public goods. We have, therefore, demonstrated the following relationship for this coefficient.

$$(8) \qquad 1 - \gamma_i = \alpha_{i,\text{private}} < \alpha_{i,\text{mixed}} < \alpha_{i,\text{public}} = 1.$$

By recalling that $\phi_i = 0$ for a private good, 1 for a pure-public good, and lies between 0 and 1 for the mixed-public good, we can see that the relationship depicted in Eq. (8) applies.

Return now to a situation in which there is a redistribution of income between the two alliance members. Andreoni shows that the change in the total contribution of the members, X, that results from this redistribution is proportional to the difference between the two α_i coefficients. It follows, therefore, that there will be neutrality with respect to the activity, X, when the coefficients are equal. The sum of the members' contributions will not be affected by income redistributions.

It is evident from Eqs. (7a) and (7b) that this will occur when both the spillover parameters and the marginal propensity to spend on alliance activities are the same for the two countries. For this special case, the total contribution will be independent of the distribution of income among the members, and we can express the total demand for alliance activities as follows:

$$(9) \qquad X = (K_a + K_b)/(1 + \phi\gamma) + (1 - \gamma)I/(1 + \phi\gamma).$$

Unless the coefficient α_i is one for both members, however, as is the case in the Olson-Zeckhauser model of pure-public goods, the change in a member's contribution will be less than the change in money income; the consumption of the non-alliance goods, Y_a and Y_b, will change accordingly. Full income and, therefore, welfare will change as a result of the redistribution.[11]

Although neutrality with respect to X is achieved when the two coefficients are equal, full neutrality is achieved only when the alliance good is pure-public. The changes in full income that occur suggest that, while there is interdependency in consumption, a familial relationship between the two members no longer exists. The use of the burden indicators presented in Eqs. (6a) and (6b), therefore, is more applicable for the mixed-public goods case than it is for the pure-public goods situation because there is no longer full neutrality in which redistributions of income change the conventional burden measure in the relevant offsetting fashion.

EMPIRICAL EVIDENCE

Most of the empirical analysis of alliance members has focused on NATO aggregate expenditure levels. For example, Todd Sandler and James Murdoch have conducted an empirical test of neutrality for the 1956-1987 period for the U.S. and NATO allies. Using a model that includes a threat variable, they conclude that the empirical evidence supports the hypothesis that military spending levels are mixed rather than pure-public goods.[12]

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[11]For the case in which the coefficients are equal for all members, Andreoni shows that the change in an individual member's contribution equals the product of the calculated coefficient and the change in national income. That part of changed national income that does not go to the change in contribution is used for other consumption. A national income gainer will receive an increase in full income, which is an index of welfare change, equal to the increase in national income less the discounted reduction in the other member's contribution. The reduction in the other member's contribution is proportional to the loss in national income, where the factor of proportionality is the coefficient α_i. This reduced contribution is discounted by the other member using the spillover parameter, ϕ_i.

[12]Todd Sandler and James Murdoch, "Nash-Cournot or Lindahl

In earlier work, they employed a model similar to Eqs. (5a) and (5b) to relate nine NATO members (including France's) annual military expenditures over the period 1961-1979 to the member's own national income during the same period and the aggregate military expenditures of other nations lagged one period. Unlike their recent work, the earlier analysis did not include a threat variable. Because Murdoch and Sandler are hypothesizing that a shift from massive retaliation to flexible response increased the private component in military expenditure, they also examined whether there was a change in the spillover parameter for the years 1974-1979.

From Eqs. (5a) and (5b), we see that the marginal propensity to spend, $1 - \gamma_i$, is the coefficient of national income, and the aggregate spillin parameter, ϕ_j, equals (minus) the coefficient of the aggregate military expenditures of other nations divided by γ_i. Table 2 summarizes the parameter estimates obtained in their analysis for the 1974-1979 time period.

These results suggest that the United States received a large spillover from the NATO allies during this time period. The allies, however, did not receive much spillover from other members. The results obtained in this type of aggregate model, however, may not fully capture the complexities of NATO spending interactions.

Table 2

MURDOCH-SANDLER ESTIMATES OF NATO MILITARY SPENDING PROPENSITIES AND SPILLOVER PARAMETERS, 1974-1979

Nation Parameter	United States	France	United Kingdom	Belgium	Netherlands	Denmark	Norway	Germany	Italy
Marginal Propensity to Spend	.035	.015	.015	.017	.017	.007	.024	.007	.025
Spillover	.734	.009	.009	-.004	-.004	-.004	-.002	-.040	.010

SOURCE: James C. Murdoch and Todd Sandler, "Complementarity, Free Riding, and the Military Expenditure of NATO Allies," Journal of Public Economics, 1984, pp. 83-101.

Behavior?: An Empirical Test for NATO Allies," *Quarterly Journal of Economics* (forthcoming).

Each nation's reaction may actually be to the detailed characteristics of a nation's military posture; that is, to various measures of force structure, modernization, readiness, and sustainability. For example, the interactions between each member's tactical aircraft may reflect a substitution relationship. Others, such as between tactical aircraft and ground-based air defense assets, may reflect a complementarity relationship [13]

The interactions, therefore, might actually be between the various types of military (and support) capital stocks rather than between aggregate spending. One might also consider the possibility that equipment stocks are gradually adjusted over time. The annual spending on stocks might thus best be characterized by a stock adjustment process in which one only partially moves to the desired level in a particular year. Also, there might be an adaptive expectations process in which spending in some year depends on the other members' long-term activity levels rather than these levels lagged a single year. Finally, the parameters obtained from a linear regression equation are best viewed as average values that are applicable to the range of data employed, but which may not fully reflect interactions that occur outside this range.

All of this suggests that the interactions may typically be micro in character, and the model may not only be non-linear, but may also have a lag structure that is much more complicated than represented by a simple aggregate model. Nevertheless, at the highest planning levels, aggregation concepts must be available to understand the broad interactions and trade-offs. Further analysis is required, therefore, of the private spending phenomenon depicted in Table 2.

We suggest that it would be appropriate to conduct a detailed analysis of the characteristics of alliance goods to include all admissible activities of the members. Econometric methods would need to be augmented with other techniques to include surveys and the use of subjective assessment techniques. This type of analysis would be required to properly calculate measures of burden using Eqs. (5a) and (5b).

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[13]The conceptual aspects of substitutions versus complementarities are discussed in Murdoch and Sandler, "Complementarity, Free Riding, and the Military Expenditure of NATO Allies," op. cit.

V. CONCLUSION

The striking neutrality implication of the Olson-Zeckhauser model indicates that measures of burden-sharing need to be carefully interpreted when the pure-public goods model is used to analyze alliance activities. Redistributions of income, such as those resulting from changes in the terms of trade, change the conventional measure of burden that is defined as the share of a member nation's income devoted to defense activities, but do not change either the level of total provision of the alliance good or the consumption of non-alliance activities.

Many observers of alliance activities may, however, be unwilling to accept the implication of the Olson-Zeckhauser that redistributions of income among alliance members do not have any real effect on national well-being. It is probably more realistic to view the goods provided by alliance members as mixed-public goods that contain both public and private characteristics. Spending equations are illustrated that permit one to estimate the spillover parameters, and we also suggest a measure of burden that depends, in part, on these parameters. The suggested measure--spending that spills over to others divided by full income--is appealing. In the mixed-public good case, the effects of redistributions of income are sufficiently complex that the suggested burden ratio remains an interesting measure of the cost borne by each member.

It is also noteworthy that the spillover parameters of both nations enter the calculation. Although we believe that the nation whose activity spills over has more effect on its extent than the receiving nation, we are far from being able to determine the effect of each nation's actions on the size of the parameters.

Although Sandler-Murdoch analysis of aggregate spending interactions indicates that NATO allies' military spending is predominantly private, there are a number of uncertainties associated with this type of analysis. To proceed further, additional work is needed on the nature of the characteristics valued by the alliance

members, and how these are affected by each member's actions. We hope that this type of analysis will permit the more effective measurement of the spillover parameters in order to implement the suggested burden measure.

We have not addressed in any depth the issue of equitable burden-sharing among alliance members. We believe, however, that our discussion of neutrality as it relates to the Cournot-Nash solution and our brief comments on social welfare functions bear on this issue.